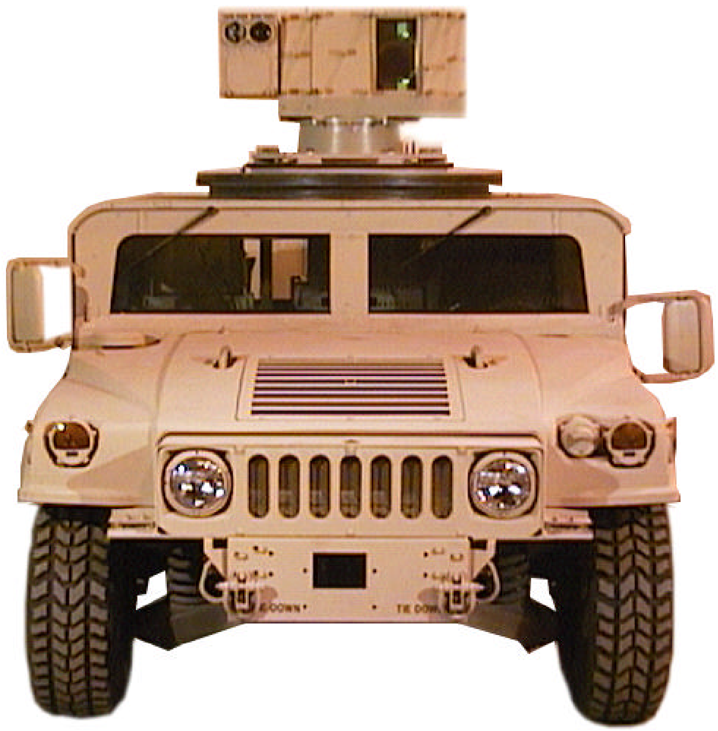
ESTCP
Cost and Performance Report

(UX-9909)



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COST & PERFORMANCE REPORT
ESTCP Project: UX-9909

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ADM	area denial munition
AFB	Air Force Base
Am	amino
ARTS	all-purpose remote transport system
AVS	armored vehicle system
BCS	beam control system
BLU	bomb live unit
BO	explosive material/burnout
C	celsius
C-4	a type of explosive
CAD	Chromatographic Analysis Division
cm	centimeter(s)
CO2	carbon dioxide
CW	continuous wave
DNB	dinitrobenzene
DNT	dinitrotoluene
DoD	Department of Defense
EOD	explosive ordnance disposal
EOD/LIC	Explosive Ordnance Disposal/Low Intensity Conflict
ESTCP	Environmental Security Technology Certification Program
FCS	fire control subsystem
H-LONS	HMMWV laser ordnance neutralization system
HMMWV	high mobility multipurpose wheeled vehicle
HMX	high melting explosive
HO	high order detonation
HPLC	high performance liquid chromatography
IFM	Influence Fuzing Munition
lb	pound(s)
LCS	laser chiller subsystem
LDS	laser device subsystem
LNS	laser neutralization system
LO	low order detonation
LPS	laser power subsystem
LSRB	Laser Safety Review Board

m	meter(s)
mm	millimeter(s)
mW	milliwatt(s)
NAVEODTECHDIV	Naval Explosive Ordnance Disposal Technology Division
NB	nitrobenzene
Nd:YAG	neodymium: yttrium aluminum garnet
NR	no reactons
NT	nitrotoluene
NTTR	Nevada Test and Training Range
PBX	plastic bonded explosive
PBXN-107	a type of explosive
POC	point of contact
PPS	prime power subsystem
RDX	Royal Demolition Explosive
RTTC	Redstone Technical Test Center
SMDC	Space and Missile Defense Command
TA-6	Test Area 6
TNB	trinitrobenzene
TNT	trinitrotoluene
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
UXO	unexploded ordnance
W	watt(s)
W/cm^2	watts per square centimeter

ACKNOWLEDGEMENTS

We would like to express appreciation to John Schiavone of Sparta Inc, for his efforts on this demonstration and for providing thoughtful insight in overseeing the development of the H-LONS equipment. Our thanks also go to the other Sparta employees who helped with this effort especially Owen Hofer, Daryl Hancock, and Scott McKenzie. The efforts of the test facility operators are greatly appreciated, especially Tony Crutcher at TA-6, for his willingness to continue testing into the weekend. Acknowledgment is extended to Thomas O'Reilly for his effort on this demonstration from the beginning, for persisting through the discouraging development problems, and for his contributions to the writing of this report. Finally, appreciation is extended to Scott McPheeters and Bob Snead of Space and Missile Defense Command (SMDC). Without their generosity in sharing their laser, this demonstration would not have produced any results. This demonstration was supported by the Environmental Security Technology Certification Program (ESTCP), the Navy Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV), and the Office of Explosive Ordnance Disposal/Low Intensity Conflict (EOD/LIC).

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

Current methods to clear small ordnance items, such as submunitions, from ranges involves the use of individual explosive ordnance disposal (EOD) personnel to place a block of plastic explosive next to each item, which then detonates the unexploded ordnance (UXO). In addition to being a costly, dangerous and labor-intensive job, the use of additional explosives introduces pollutants to the environment and subjects EOD personnel to close contact with explosive materials and hazards.

Development of technology to neutralize UXO with a high-power laser has been underway for roughly 15 years. Advances in laser technology have enabled the construction of a next-generation mobile laser neutralization system, the high mobility multipurpose wheeled vehicle (HMMWV)-mounted laser ordnance neutralization system (H-LONS). Use of the new H-LONS to neutralize UXO is expected to reduce the cost of range clearance by reducing manpower needs and exposure to explosive hazards.

1.2 OBJECTIVES OF THE DEMONSTRATION

The purpose of this demonstration is to evaluate the H-LONS as a means of UXO remediation on active military training ranges. The principal objective is to demonstrate that H-LONS can perform range clearance tasks in a manner that uses less manpower, that is safer for operators, and that is less environmentally damaging than the current range clearing method. Secondary objectives include demonstrating the potential to greatly reduce the amount of C-4 and other demolition materials used in clearance operations and to reduce the amount of solid waste and explosive residue generated by clearance operations.

The demonstration consisted of two scenarios performed over the course of several months. The first involved using H-LONS in a controlled setting to neutralize submunitions and other small ordnance items that were placed by hand. The other involved using H-LONS to perform clearance operations on active submunition target ranges, in place of or in addition to conventional UXO clearance teams. The demonstrations took place, respectively, at Redstone Arsenal, Alabama, and Nellis Air Force Base (AFB), Nevada.

1.3 REGULATORY DRIVERS

In February of 1997, the Environmental Protection Agency used its powers under the Safe Drinking Water Act to issue the first of four administrative orders concerning Camp Edwards in Massachusetts. These orders, based on the detection of the Royal Demolition Explosive (RDX) in the groundwater, required many feasibility studies and even the cessation of certain training activities, pending the completion of environmental investigations at the training ranges and impact area. The Department of Defense (DoD) is concerned that these actions may be applied to range sites in other regions as well. Any new neutralization techniques should take these administrative orders into account.

The use of lasers is subject to safety rules and regulations intended to prevent damage to the eyes and other parts of the body from laser exposure. These rules and regulations were strictly observed during all phases of the demonstration. Laser eye-safe footprints were evaluated and submitted for approval from the appropriate authorities.

Use of the laser for experimental and demonstration purposes did not require the approval of the DoD Laser Safety Review Board (LSRB) or the DoD Explosive Safety Board.

All operations on target ranges and other UXO contaminated areas were subject to additional safety regulations. Demonstration procedures were designed to comply with all regulations in effect at the test sites.

Classification of test results is governed by OPNAVINST S5513.3B-24.2, *Explosive Ordnance Disposal Nonnuclear Security Classification Guide.* Most of the test data is not classified, but results for certain categories of munitions are. Those categories are area denial munitions (ADM), influence munitions, long-time delay fuzing, and antiremoval/antiwithdrawal devices. Data that reveals the application of clearance procedures to specific items in the four categories above in the armed or considered armed conditions is Confidential. Some items H-LONS has been used against are either area denial munitions or have influence fuzing. As a result, the actual nomenclature of these items is not shown in this report. Instead, the names have been replaced with generic terms referring to the category of munitions, such as ADM-1, IFM-1.

1.4 DEMONSTRATION RESULTS

The data show that H-LONS can perform range clearance tasks as stated in the objectives. H-LONS neutralized all 609 targets with no laser-related problems. Targets were neutralized in a range of engagement times of 2 to 463 seconds fired from engagement ranges of 21 to 100 m. Generally, the farther the engagement range, the greater the engagement time. The munitions reacted in either a low order detonation or a burnout of explosives, usually depending on the type of munition lased or its condition when lased. In general, the laser neutralizations showed explosive residue amounts in magnitudes of hundreds, thousands, and ten thousands greater than those left by the current method. All the secondary criteria of not generating process waste, ease of use, and versatility were met. Over the course of the demonstration, the vehicle required numerous minor maintenance repairs, but the maintenance did not affect the laser and its performance.

1.5 STAKEHOLDER/END-USER ISSUES

The administrative orders at Camp Edwards must be considered when new ordnance neutralization techniques are introduced. Measurement of explosive byproducts needs to comply with the Safe Drinking Water Act. Laser neutralization of submunitions leaves more RDX in the environment than the current counter charge method. However, laser neutralization is a far less hazardous range clearance method than counter charging. Residual RDX levels are many orders of magnitude lower than would result from rainwater entering the submunition and leaching out the RDX.

An issue for end users, mainly EOD units, is the initial cost of fielding the system. A laser neutralization system (LNS) would be the most expensive piece of equipment used by any EOD unit. The added costs of maintaining an up-armored HMMWV, especially one used exclusively for laser negation, is beyond most units' current fiscal boundaries. Furthermore, the technology is in its infancy where costs could eventually decrease while the capabilities could increase.

EOD personnel have not operated the H-LONS long enough to develop formal neutralization procedures. Sparta personnel conducted most of this demonstration. Additional experience must be obtained before the system can be recommended for service use or acquisition action by PMS-EOD.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

2.1.1 Laser Neutralization

Laser neutralization of UXO is accomplished by using a focused laser beam to heat the case of an ordnance item to a high temperature. The heat from the outer surface of the case is conducted to the inside of the case, and from the inside of the case to the explosive filler material. When the explosive filler material is heated above its ignition temperature, rapid combustion (deflagration) of the filler occurs. When sustained combustion of the explosive filler begins, the munition will be neutralized by one of several different processes, depending on the case material, type, and construction of the munition, the laser power, flux density (power divided by spot size, in watts per square centimeter), and beam quality of the laser.

Submunition cases are typically made of thin metal. If the case is thin or the flux density is high, the case will generally burst at the laser aiming point because the tensile strength of the case will be reduced at that location. A diagram of the mechanism for thin-walled metal munition cases is shown in Figure 1. If, on the other hand, the munition case is thicker or the flux density is lower, the case will rupture at an existing weak spot. A diagram of this mechanism is shown in Figure 2.

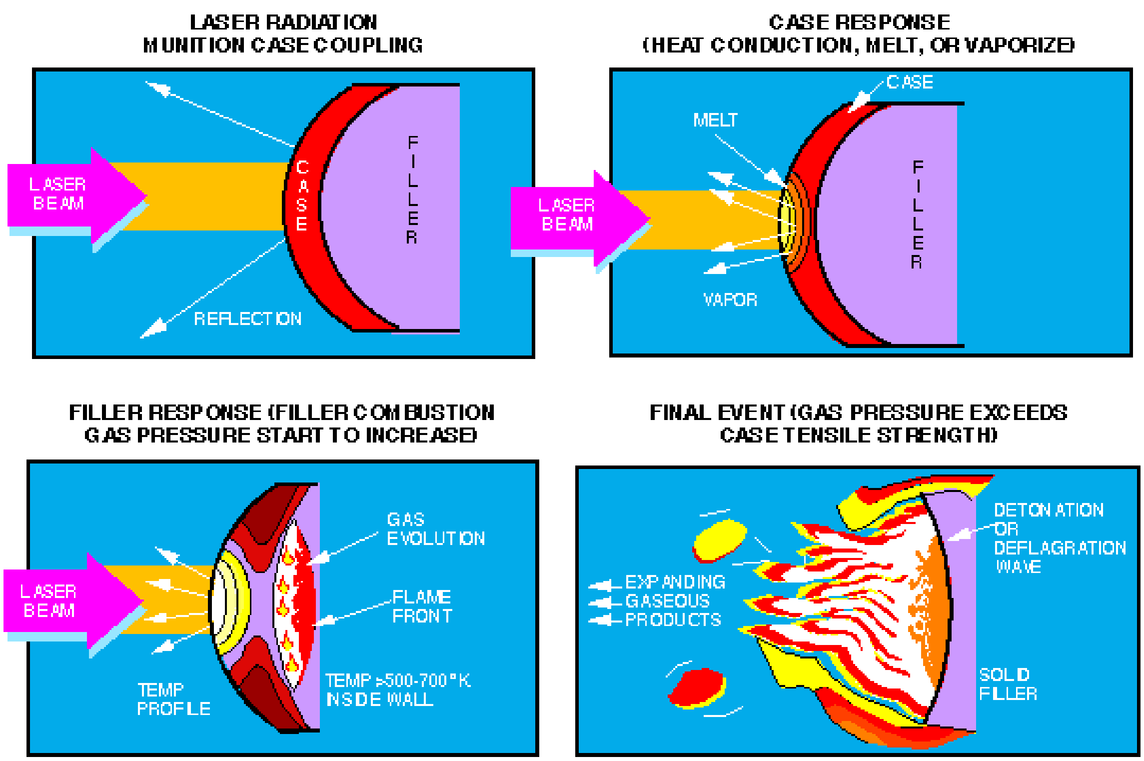


Figure 1. Thin-Walled, Metal-Cased Munition Neutralization Mechanism.

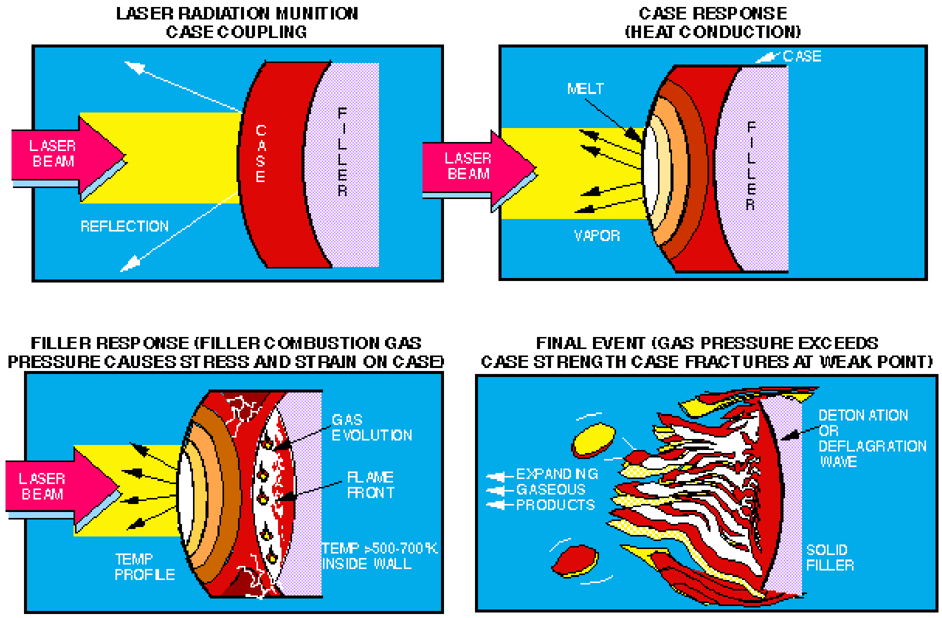
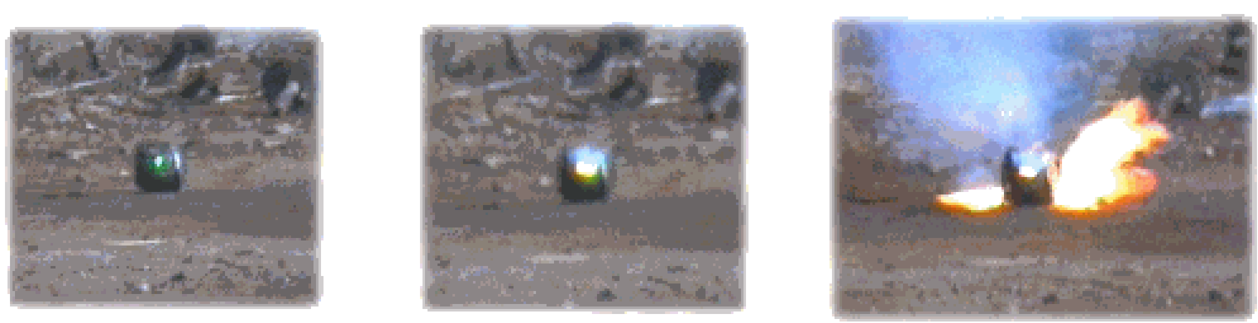


Figure 2. Thick-Walled, Metal-Cased Munition Neutralization Mechanism.

If the munition case does not contain the combustion gases, there will be no rapid buildup of pressure internally, and the munition will burn until the flame front reaches more thermally sensitive explosives in the fuze or detonator. These will then detonate, initiating and consuming any remaining filler in the case. A series of pictures describing the neutralization of such a munition is shown in Figure 3. A low power tag laser is used for aiming purposes prior to the more powerful negation laser.



Tag Laser on BLU-63 *Negation Laser on BLU-63* *BLU-63 Neutralized*

Figure 3. Munition with Tag Laser Illumination, Negation Laser Irradiation, and Combustion Initiated.

The laser power needed to neutralize ordnance varies depending on the type of munition. Neutralization of small items such as submunitions and mines can be accomplished with a 350 W laser with a flux density greater than 50 W/cm^2. Neutralization of larger bombs or items with thicker cases requires approximately 1,000 W of power. In addition to the power requirement, the laser must be focused to a spot small enough to produce a flux density in excess of 350 W/cm^2. The maximum negation range of the LNS depends of the type of ordnance engaged, the flux density, and power placed on the munition.

2.1.2 Hardware

H-LONS is mounted on an up-armored HMMWV and consists of seven subsystems: (1) armored vehicle, (2) prime power, (3) fire control, (4) beam control, (5) laser device, (6) laser power, and (7) laser chiller. All subsystems are mounted on the HMMWV and all power is produced by the onboard systems. The location of these subsystems on the armored vehicle is shown in Figure 4, except for the laser power subsystem, which is located behind the driver's seat.

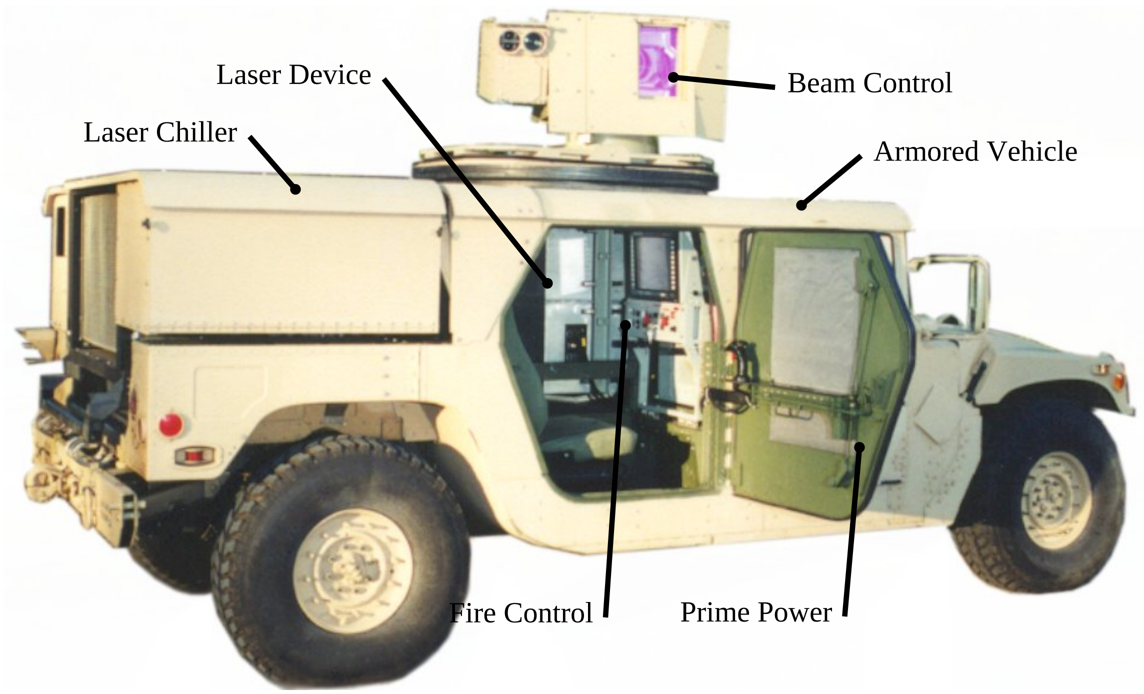


Figure 4. H-LONS Hardware Configuration.

The armored vehicle subsystem (AVS) is a modified up-armored HMMWV, the platform to which all the other subsystems are mounted. The prime power subsystem (PPS) generates 22 kW of 60 Hz AC electrical power from a generator driven by the AVS transmission and is used to operate the laser chiller and laser power subsystems.

The fire control subsystem (FCS) consists of a computer, displays, joysticks, VCR, and other equipment required to control and monitor operation of the laser and support systems. The beam

control subsystem (BCS) is an actively stabilized gimbaled platform and control electronics, and is used to aim the laser and other sensors at targets.

The laser device subsystem (LDS) consists of an optical bench to which the lasers, laser beam combining optics, laser beam shaping optics, laser beam dump for the negation laser, and beam expander are mounted. The tag laser, used to designate targets prior to firing the negation laser is a diode-pumped, continuous wave (CW) doubled neodymium: yttrium aluminum garnet (Nd:YAG) laser producing 200 milliwatts (mW) of power with a wavelength of 0.532 microns. The negation laser is a diode-pumped quasi-CW Nd:YAG laser with a 1.064 micron wavelength producing 785 W. The laser power subsystem (LPS) consists of a power supply and a diode driver and provides the proper electrical current, voltage, and waveform to the diodes in the LDS. The laser chiller subsystem (LCS) chills water for the LDS and the LPS.

2.2 PREVIOUS TESTING OF THE TECHNOLOGY

2.2.1 Integration Testing

During integration testing at Redstone Arsenal, Huntsville, Alabama, in January and May 1999, H-LONS demonstrated the capability to neutralize ordnance at distances from 30 m to 250 m. During the May test period, the system operated with no major problems and neutralized 213 ordnance items over a 5-day period. Ordnance neutralized included the Mk 118 Rockeye, M42, bomb live unit (BLU) 26, BLU 63, BLU 97, and several types of metal and plastic cased mines.

The type of reaction seen varied by munition. Mk 118 Rockeye submunitions tended to break up into a few large pieces that needed to be reengaged to burn out remaining explosive material. BLU 26 and BLU 63 baseball-style submunitions generally burned out consuming all explosive filler. M42 grenade submunitions generally detonated. BLU 97 combined effects submunitions typically exploded in a low order reaction that consumed all explosive material, leaving large pieces of the case near the original location of the item. Metal-cased mines generally broke up into large pieces, and plastic mines typically burned out.

Although the system was able to neutralize ordnance at 250 m, negation times at this distance were long and it was difficult to clearly see ordnance even with the zoom capabilities of the camera. A more realistic upper limit for neutralization range is between 100 m and 200 m, depending on the type of ordnance.

2.2.2 First Phase ESTCP Demonstration

The system was used for three 1-week periods from August to October 1999. A variety of problems with the laser device and other subsystems prevented reliable system operation. As a result, the first phase of the Environmental Security Technology Certification Program (ESTCP) demonstration was stopped ahead of schedule, so the laser upgrade could begin. The first demonstration phase is discussed in greater detail in *Interim Report Laser Neutralization of Hazardous UXO* [1].

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

LNS technology has several advantages over current clearance methods. It is expected that use of laser neutralization can reduce the overall cost of range clearance operations. Cost savings will come from reduced personnel requirements, reductions in the amount of support equipment needed, and reductions in the amount of demolition supplies used.

Typical submunition clearance operations employ eight to twelve EOD technicians, three support trucks, one or two all terrain vehicles, and a support trailer. H-LONS clearance operations will require two personnel in the vehicle and a field supervisor in a separate trailer located outside the target area to record and analyze telemetry from the mission. This reduces human exposure to UXO and demolition material hazards, reduces the human footprint in the target area, and allows the EOD technician to neutralize high threat UXO at a safe standoff distance.

It is expected that H-LONS will be capable of locating and destroying any small, unexploded ordnance items visible on the surface, eliminating the need to use conventional demolition materials and methods for those items. This feature is of particular interest in clearance of submunitions, as small ordnance items like these tend to remain on the surface after impact. This capability is expected to allow H-LONS to rapidly clear large numbers of UXO from submunition target zones.

The dramatic reduction in use of bulk demolition material will proportionally reduce the amount of solid waste material generated with each operation. Typical 1-week submunition clearance operations generate approximately 30 cubic yards of solid waste, mostly packing material from demolition supplies (explosives, detonators, fuzes, etc.).

In addition to solid waste, the use of demolition materials like C-4 in conventional clearance methods increases the total amount of explosive detonated or burned on the range. This may result in additional explosive residue and by-products being left in the soil, may produce additional airborne pollution, and certainly creates more noise and blast overpressure. Remnants of fuzes, fuze lighters, and detonators are all considered hazardous waste and must be periodically gathered up and disposed of at high cost.

The main disadvantage of LNS technology is that the initial cost of each system is high. Additionally, the use of high-power lasers on small, light vehicles is relatively new. Although the development and production costs for a vehicle mounted system are high, it is believed that the speed and efficiency of such a system will make use of LNS to perform range clearance operations more cost-effectively than continuing to use existing clearance techniques.

There is no comparable technology currently in use, although the Air Force Research Lab is developing a similar system that will use a carbon dioxide (CO_2) laser mounted on an all-purpose remote transport system (ARTS) platform. That effort is still early in the research stage. All current UXO neutralization techniques rely on the use of explosives or propellants to provide energy to neutralize UXO. Laser neutralization is the only technology in development that can reliably neutralize UXO at safe standoff distances without the use of explosives or propellants.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The primary performance objectives are listed below in Table 1.

Table 1. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)
Qualitative	Reduce human contact	Less exposure time
	Prevent additional explosive pollution	Eliminate demolition explosive materials
	Reduce environmental damage	Less physical damage due to low order reaction
Quantitative	Reduce time to clear submunitions	<Current procedure
	Reduce manpower required for range clearance operations	2-3 person team opposed to 8-12
	Reduce explosive residue	Less explosive residue in soil

The system was demonstrated in two different scenarios. The first demonstration scenario used H-LONS in a controlled setting to neutralize items taken from inventory and placed at specific distances and orientations relative to it. The second scenario involved range clearance operations where the objective was to use H-LONS in real-life, practical applications.

3.2 SELECTING TEST SITES

Test Area 6 (TA-6) on Redstone Arsenal, Huntsville, Alabama, operated by Redstone Technical Test Center (RTTC) was selected to perform the first scenario of the testing. It is laser-safety approved, has facilities for observing demonstrations, is accessible to all project participants, and is capable of detonating large ordnance.

Nellis AFB was selected as the main demonstration site because of the large quantity of submunition UXO generated (18,000 each year, on average) and an operational requirement to clear UXO from the target grids. The Nellis EOD flight has also shown a commitment to advancing technology to make the mission safer and more efficient.

3.3 TEST SITE HISTORY/CHARACTERISTICS

Test site TA-6 has been used to perform laser neutralization of UXO, landmines, submunitions, mortars, artillery rounds, general-purpose bombs, and rifle grenades since 1994. It has laser safety approval and can handle ordnance up to 500 lb. The site also has electricity, communication lines, and a blockhouse to observe the ordnance neutralization processes. The site has the capability to measure the blast overpressure and obtain air and soil samples for analysis.

The following area was used predominately in Phase I. Approximately 250 m from the blockhouse in TA-6, several grids contain dirt, sand, and concrete surfaces, where the demonstrations were performed. Figure 5 shows a site layout for Phase I testing at Redstone Arsenal, Alabama. The area behind the grids is high ground used because the previous laser had a large eye safety footprint.

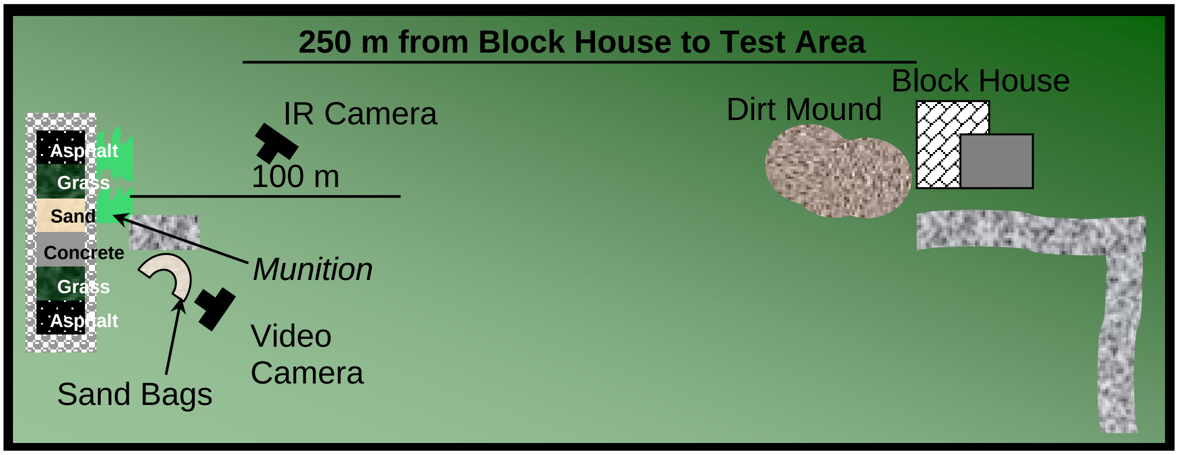

Figure 5. TA-6 Test Range Layout.

The Nevada Test and Training Range (NTTR) is made up of millions of acres of range complex with more than 800 target sites. It is located in the Nevada desert northwest of Las Vegas. Three areas, range 63 target 4 (63-4), range 62 target 1 (62-1), and range 75 target 46 (75-46) are the NTTR submunition targets. The most common submunition encountered is the BLU 97 combined effects munition. The BLU 97 is a dual-purpose, anti-vehicle, anti-personnel submunition released in large numbers from airdropped dispensers.

3.4 PHYSICAL SETUP AND OPERATION

The target sites used in this demonstration are cleared of UXO every 50 days or 100 submunition dispensers, whichever comes first. Times for the demonstrations were scheduled in conjunction with other range clearance activities. An EOD team visited the site, determined the extent of UXO contamination, and identified areas of heavy UXO concentration.

A three- or four-person team deployed H-LONS and a support trailer to an area near the site but out of the danger area. H-LONS requires a crew of two and at least one other person to operate the telemetry equipment used to monitor the demonstration. All equipment related to the demonstration was contained within either the support trailer or H-LONS.

H-LONS was used during daylight hours on the range. H-LONS was not intended to be used during rain, snow, or dust storm conditions; however, it performed well during the rain at TA-6. It was believed that weather could have a negative impact on laser performance though light rain and wet conditions were acceptable. A reflective danger zone of 200 m was maintained around the laser for eye safety. The windows in H-LONS are laser-safe so no goggles were required inside the vehicle.

3.5 SAMPLING/MONITORING PROCEDURES

After each neutralization experiment, duplicate surface soil samples were collected in the region of disturbed soil. Each sample was a surface composite of at least four discrete samples collected with a hand shovel in the depth region 0–2.5 cm. The discrete samples were combined in an aluminum pan and thoroughly mixed. A representative subsample was obtained by coning and quartering as described in detail in Jenkins et al (1996) [4] and placed in a clean 250 ml amber glass bottle. The hand sampler was cleaned by immersion in acetone between sampling events to eliminate the possibility of analyte carryover from sample to sample.

Each sample, as described above, included discrete samples taken from any crater resulting from the neutralization. Composite samples are being proposed in this study because results from two studies conducted at explosives-contaminated firing ranges have demonstrated enormous heterogeneity in explosives concentrations in soil over very short distances (Jenkins et al 1997, 1998 [5], [6]). Composite samples were shown to be more representative than discrete samples with the extent of heterogeneity found.

The surface soil in the vicinity of the neutralization was also visually inspected to determine if any suspect residues were visible, and if so, samples of these suspicious regions were collected as well.

Samples were placed in a cooler on ice and returned cold to the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) Chromatographic Analysis Division (CAD) laboratory by overnight carrier. Upon receipt, samples were kept frozen until extracted and analyzed. Extraction was conducted at the discretion of the laboratory.

With each batch of samples, one baseline soil, one sample duplicate for each four samples, one spiked blank soil, and one sample matrix spiked sample were extracted and analyzed. Results from these samples ensure that analyte recovery is adequate and that the methods are not being influenced by interferences from nontarget analytes.

The explosive present in BLU 97 bomblets is either the explosive PBXN 107 or cyclotol. The plastic bonded explosive (PBX) is 86% RDX and 14% plasticizer. The cyclotol is 70% RDX and 30% trinitrotoluene (TNT). Since RDX and TNT are the only high explosives present, the target analytes will be RDX and its manufacturing impurity HMX and TNT, and its manufacturing impurities and environmental transformation products (TNT, 2,4-dinitrotoluene [DNT], 2,6-DNT, 1,3-dinitrobenzene [DNB], 1,3,5-trinitrobenzene [TNB], 2-Amnio [Am]-4,6-DNT, 4-Am-2,6 DNT, nitrobenzene [NB], 2-nitrotoluene [NT], 3-NT, and 4-NT). These analytes are the target analytes of CAD 55.1.

Soil samples were thawed and homogenized. A representative 2 g portion of each was placed in a 40 ml amber glass vial and 10 ml of high performance liquid chromatography (HPLC) grade acetonitrile added. The samples were dispersed with a vortex mixer for 30 seconds and extracted in an ultrasonic bath for 18 hours. The bath was maintained at room temperature throughout the extraction period. Then, the samples were allowed to settle for at least 30 minutes, and the extracts were mixed 1:1 with aqueous calcium chloride solution to assist in the flocculation of suspended material. The extracts were then filtered through a disposable Milex SR filter unit

(0.5 µm). The resulting extracts were maintained at 4°C until analyzed, which occurred within 7 days of extraction.

3.6 ANALYTICAL PROCEDURES

Samples were initially analyzed using USACHPPM CAD 55.1. This is a reversed-phase HPLC method and provides detection limits for RDX and TNT of approximately 0.25 mg/kg. Extracts were initially analyzed on a primary HPLC column. If target analytes appeared to be present, these extracts were then analyzed on the confirmation column.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

The H-LONS neutralized all 609 submunition and mine targets it shot. It performed well enough to attempt other types of targets such as 2.75-in rockets with white phosphorous rounds and a 120-mm mortar, all with thick shells. These munitions did not neutralize, but they were not within the scope of this demonstration. They were available targets shot with the idea of putting usage hours on the new laser.

4.1.1 Scenario 1, Emplacement and Soil Sampling, September 23-28, 2002

Scenario-1 testing involved placing ordnance at distances of 25 m, 50 m, and 75 m at varying beam entry angles with multiple trials of each. Additionally, scenario 1 involved lasing four BLU-97s—two each at 25m and 75m—and detonating two BLU-97s with C-4 and taking soil samples of each. Some deviations from the original plan occurred primarily because of the readily available supply of targets. Some munitions were plentiful while others were not. Some munitions were used that were not a part of the original plan but were readily available and within the same family of ordnance.

4.1.1.1 Emplacement

Tables 4.3 through 4.12 of *Laser Neutralization of Hazardous UXO Final Report* [9] completely depict the results of each munition type. All targets shot were neutralized in some capacity by either low order detonation (LO), high order detonation (HO), or explosive material burnout (BO), leaving the UXO case intact. The BLU-97, 40mm grenade, M42, ADM-3, ADM-4, and Mk 118 Rockeye primarily resulted in low order detonations. The 60mm mortar reacted with a high order detonation. ADM-1/ADM-2, ADM-5, ADM-6, and ADM-7 resulted in burnout reactions. Many of the burnout reactions eventually resulted in a final low order detonation.

Table 2. Reaction Type for Each Submunition Tested.

Munition Type	Low Order	Burn Out	High Order
ADM-1	25	25	0
ADM-2	5	3	0
ADM-3	23	0	3
ADM-4	7	0	1
ADM-5	4	5	1
ADM-6	0	4	0
ADM-7	0	3	0
BLU-97	36	1	3
M42	27	0	1
40mm	24	0	0
60mm	0	0	8

Lasing times varied on many of the ordnance types. For example, back-to-back BLU-97 shots ranged from 5 seconds to 265 seconds at the same distance and at the same engagement angle. Despite this range of scatter, some general trends could be observed. Table 3 lists each UXO with its average lasing time at 25 m, 50 m , 75 m, or 100 m intervals corresponding with engagement angles of 0°, 22.5°, 45°, 90°, or 180°. Generally, longer distances required more lasing time on each type of ordnance. The most optimum angle of engagement appears to be 90°. Ordnance types that react in a burnout reaction generally require more lasing time than low order reacting ordnance, primarily to verify that the burn out is sustained and will continue until the explosive is extinguished.

Table 3. Average Engagement Range Versus Engagement Angle for Each Munition.

	BLU-97				
	Initial Firing Angles (deg)				
Firing Ranges (m)	**0**	**22.5**	**45**	**90**	**180**
25	136.0	54.0	25.0	33.9	
50	123.5		43.5	72.1	
75			322.5	48.5	
100				161.5	

	40mm Grenade				
	Initial Firing Angles (deg)				
Firing Ranges (m)	**0**	**22.5**	**45**	**90**	**180**
25		145.0	6.5	9.0	
50		48.0	11.0	21.0	
75		16.5	45.5	135.8	
100				37.5	

	ADM-1/ADM-2				
	Initial Firing Angles (deg)				
Firing Ranges (m)	**0**	**22.5**	**45**	**90**	**180**
25			171.5	183.3	
50			163.5	100.4	
75			133.0	106.7	
100				183.0	

	M42				
	Initial Firing Angles (deg)				
Firing Ranges (m)	**0**	**22.5**	**45**	**90**	**180**
25	11.5		4.5	2.0	2.0
50	7.5		28.5	3.0	2.5
75			11.0	8.0	
100				11.0	6.0

	60mm Mortar				
	Initial Firing Angles (deg)				
Firing Ranges (m)	**0**	**22.5**	**45**	**90**	**180**
25					
50				9.0	
75				31.2	
100					

	ADM-3				
	Initial Firing Angles (deg)				
Firing Ranges (m)	**0**	**22.5**	**45**	**90**	**180**
25				7.0	
50				17.5	
75			36.0	19.9	
100				25.0	

Table 3. Average Engagement Range Versus Engagement Angle for Each Munition.
(continued)

	ADM-4 Initial Firing Angles (deg)					
		0	22.5	45	90	180
Firing Ranges (m)	25					
	50				123.3	
	75				142.0	
	100				112.0	

	ADM-5 Initial Firing Angles (deg)					
		0	22.5	45	90	180
Firing Ranges (m)	25					
	50					
	75				164.0	
	100				186.0	

	ADM-6 Initial Firing Angles (deg)					
		0	22.5	45	90	180
Firing Ranges (m)	25					
	50				100.0	
	75					
	100					

	ADM-7 Initial Firing Angles (deg)					
		0	22.5	45	90	180
Firing Ranges (m)	25					
	50				73.3	
	75					
	100					

4.1.1.2 Soil Samples

Soil sample results were received from USACHPPM and presented as Tables 4.14 through 4.16 in the final report. The laser samples are identified with an L-25 m or L-75 m for 25 m, and 75 m shots, respectively. Similarly, the C-4 shots are so indicated. The sample location is identified by A, B, C, or D. The A samples were taken from the center of the crater, B samples from the edge of the crater, C samples from four collection pans 5 feet away, and D samples from eight collection pans 10 feet away. The results are shown in Table 4.

All samples contained 2,4,6-TNT and RDX. All laser samples and five (of eight) C-4 samples contained reportable amounts of high melting explosive (HMX). Two laser samples contained reportable amounts of 2,4-DNT and 1,3,5-TNB. In general, the laser neutralizations showed explosive residue amounts in magnitudes of hundreds, thousands, and ten thousands greater than those left by the current method. The largest difference and the area where the most explosives were present were the D samples, taken the farthest distance away from the munition crater. Also, the presence of 2,4-DNT and 1,3,5-TNB occurred in D samples. The area with the least amount of explosive was taken at the edge of the crater (B samples).

4.1.2 Scenario 2, Active Range Clearance, December 3-6, 2002

Scenario 2 testing involved using the H-LONS in actual clearance operations. The operators approached the targets from the command post, stopped the vehicle, then proceeded to neutralize

Table 4. Soil Samples with Explosive Analytes μg/g.

Field ID	DLS ID	2,4-DNT	1,3,5-TNB	2,4,6-TNT	RDX	HMX
10-L-25-A	6489001	< 2.5*	< 2.5*	**1600**	**4000**	**280**
10-L-25-B	6489002	< 0.20*	< 0.050	**120**	**300**	**21**
10-L-25-C	6489003	< 10*	< 2.5*	**4800**	**12000**	**1300**
10-L-25-D	6489004	**15**	**3.6**	**15000**	**11000**	**1800**
11-L-25-A	6489005	< 2.5*	< 2.5*	**1600**	**3600**	**420**
11-L-25-B	6489006	< 0.20*	< 0.050	**90**	**270**	**22**
11-L-25-C	6489007	< 10*	< 2.5*	**3800**	**8800**	**770**
11-L-25-D	6489008	< 10*	< 2.5*	**5400**	**12000**	**1100**
12-L-75-A	6489009	< 2.5*	< 2.5*	**640**	**1800**	**120**
12-L-75-B	6489010	< 2.5*	< 0.10*	**200**	**490**	**37**
12-L-75-C	6489011	< 10*	< 2.5*	**2800**	**6800**	**590**
12-L-75-D	6489012	**14**	**3.0**	**13000**	**12000**	**1500**
13-L-75-A	6489013	< 2.5*	< 2.5*	**360**	**1400**	**74**
13-L-75-B	6489014	< 2.5*	< 0.10*	**210**	**540**	**42**
13-L-75-C	6489015	< 10*	< 2.5*	**3700**	**9100**	**730**
13-L-75-D	6489016	< 10*	< 2.5*	**2800**	**7600**	**530**
14-C4-25m-A	6489017	< 0.050	< 0.050	**0.98**	**2.5**	**0.38**
14-C4-25m-B	6489018	< 0.050	< 0.050	**0.49**	**0.95**	< 0.20*
14-C4-25m-C	6489019	< 0.050	< 0.050	**0.20**	**0.88**	< 0.20*
14-C4-25m-D	6489020	< 0.050	< 0.050	**0.63**	**8.8**	**0.24**
15-C4-75m-A	6489021	< 0.050	< 0.050	**0.31**	**0.99**	< 0.10
15-C4-75m-B	6489022	< 0.050	< 0.050	**0.56**	**1.7**	**0.26**
15-C4-75m-C	6489023	< 0.050	< 0.050	**0.94**	**3.3**	**0.38**
15-C4-75m-D	6489024	< 0.050	< 0.050	**0.11**	**0.90**	**0.20**
BASELINE	6489025	< 0.050	< 0.050	**0.91**	**1.8**	**0.28**

the targets with the H-LONS vehicle. Tables 4.17 through 4.19 of *Laser Neutralization of Hazardous UXO Final Report* [9] depict the results of each day clearing the range. All targets reacted as LO, HO, BO, or NR.

During scenario 2, 405 targets were attempted and 402 targets were neutralized. All three targets that did not neutralize were 0.275-inch rockets with white phosphorous warheads. The breakdown of types of neutralized targets was: 386 BLU-97s, 1 BLU-61 "Softball", and 15 IFM-1 munitions.

The BLU-97 neutralizations ranged from distances of 20-76 m and engagement times of 2-360 seconds. The average range-versus-engagement times for BLU-97s are depicted in Table 4. Most BLU-97 neutralizations were low order detonations shot at some angle equal to or close to 90°. Some BLU-97s reacted with a burnout reaction, primarily if the target was damaged or if the target was shot in the cone (0°). As shown in Table 5, generally, the farther the distance, the longer the lasing time is needed.

Table 5. BLU-97 Results, Range and Time Averages.

Nominal Range (m)	Number of Targets	Average Time (sec)
25	165	23.4
50	200	31.9
75	21	49.2
Overall	386	34.8

The IFM-1 neutralizations were performed at distances of 28-51 m and engagement times of 9-292 seconds. Table 6 shows the average range-versus-engagement times. IFM-1s reacted in a burnout fashion with some reaching a low order detonation. As with most munitions that resulted in burnouts, some IFM-1s were lased with additional seconds after the burnout began to verify the burn would continue.

Table 6. IFM-1 Results, Range and Time Averages.

Nominal Range (m)	Number of Targets	Average Time (sec)
25	5	128.6
50	10	40
75	0	N/A
Overall	15	71.6

The BLU-61 was lased from 55 m for 65 seconds. It initially separated after just a few seconds since the munition is two halves fused together. One half was continuously lased for 65 seconds; the other half was lased for another 91 seconds to verify that the entire explosive was burned out.

4.1.3 Other Demonstrations, Fort Leonard Wood, Missouri, October 24, 2002

The H-LONS neutralized 19 ordnance items in less than 40 minutes. On another demonstration, before the visitor's day event, H-LONS neutralized 13 more targets in a similar fashion. All lasings were performed at distances of greater than 30 meters but less than 50 meters.

4.2 PERFORMANCE CRITERIA

Performance criteria was based on the primary objective: Can H-LONS perform range clearance tasks that use less manpower, that are safer for operators, and that are less environmentally damaging than the current range clearing method? Table 7 depicts the primary performance criteria for the demonstrations of interest to ESTCP.

Table 7. Performance Criteria.

Performance Criteria	Description
Contaminant reduction	The explosive present in BLU-97 bomblets is either PBXN-107 or cyclotol. The PBX explosive is 86% RDX and 14% plasticizer. The cyclotol is 70% RDX and 30% TNT. There is no need to add additional explosives.
Hazardous materials	Ordnance neutralized includes BLU-97, 40 mm rifle grenades, ADM-1/ADM-2, and M42.
Factors affecting technology performance	In the first scenario, performance was based on the matrices described in Tables 3.2, 3.3, 3.4, and 3.5 of the final report. For each munition, engagement time, laser power, distance, and the type of reaction were recorded. Soil samples were taken also. For the second scenario, engagement time, laser power, distance, and type of reaction were recorded on targets of opportunity.
Reliability	Overall reliability of the system has yet to be determined. It is known that the reliability of the previous laser diodes was poor.

4.3 DATA ASSESSMENT

The H-LONS can perform range clearance tasks in a manner that uses less manpower and is safer for operators. However, it may not be less environmentally damaging than the current range clearing method. The H-LONS met the primary criteria of eliminating hazard material by neutralizing all 609 targets, performing well in both scenarios, as well as the Fort Leonard Wood demonstration, and performing reliably with no breakdowns and 100% successes. H-LONS met the stated primary criteria, but laser neutralization left more explosive residue than conventional neutralization with added C-4. All the secondary criteria of not generating process waste, ease of use, and versatility were met. The vehicle did require numerous minor maintenance repairs, but none that affected the laser and its performance. The bottom line is that, with the H-LONS, operators can eliminate small munitions in a safe and effective manner that keeps the user away from the threat.

4.4 TECHNOLOGY COMPARISON

The primary differences between using this technology and the current method are stated previously in Section 2.4. At NTTR, H-LONS neutralized 402 targets in 3 days. A representative operation at NTTR using the current method neutralized 2,451 targets in 10 days with a crew of 9 EOD technicians. Interpolating, the H-LONS neutralized targets at 55% the rate that the current method does. However, H-LONS did not require the use of any demolition material and required the use of only one vehicle, primarily to transport the rest of the crew to the site. The H-LONS did require maintenance such as replacing a flat tire during operation. Operations would have to cease while this is happening, whereas this would not be a problem with the current method. Finally, the cost per neutralization (not counting equipment costs,

which are considerable) is less expensive for H-LONS than it is for the current method, as demonstrated in Section 5.3 of this report.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

The H-LONS study was conducted at government-controlled test sites specially constructed and permitted for demolition/explosive studies and operations. The demonstration did not incur the cost elements that would normally be associated with the remediation of UXO by a commercial organization. Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) received $170,000 from ESTCP and $120,000 from Explosive Ordnance Disposal/Low Intensity Conflict (EOD/LIC) to manage the study and contracts and report the results. Sparta, Inc. received $1.3 million to build the equipment, conduct testing, provide support at the test sites, and handle virtually every other aspect of the demonstration. Additionally, Sparta invested $2.5 million of its own funding. Thus, many of the subcategory cost elements could not be tracked per se, so estimates are provided in Table 8.

Table 8. Cost Tracking.

Cost Category	Subcategory	Costs ($)
Fixed Costs		
1. Capital Costs	Planning/preparation	40,000
	Contract with Sparta for equipment	1,100,000
	Sparta equipment cost	2,500,000
	Contract management	120,000
		Subtotal ($3,760,000)
Variable Costs		
2. Operations And Maintenance	Labor	48,000
	Materials and consumables	1000
	Utilities and fuel	300
	Equipment cost rental or lease	0
	Performance testing/analysis	125,000
	Other direct costs -Travel	11,000
		Subtotal ($185,300)
3. Other Technology-Specific Costs	Soil sample analysis	8500
		Subtotal ($8,500)
TOTAL COSTS		
		TOTAL TECHNOLOGY COSTS ($3,953,800)
		Quantity Treated (609)
		Unit Cost per item destroyed ($6,492)

5.2 COST ANALYSIS

The major cost elements for laser neutralization of hazardous UXO evolve primarily around the cost of the equipment, explosive operations, and maintenance. The costs to operate the vehicle are primarily driven by those factors that affect range operations and maintenance of the vehicle.

5.2.1 Cost of Equipment

The cost of the equipment is the most expensive aspect of laser neutralization. It is orders of magnitude greater than other aspects. The vehicle and it various subsystems were jointly funded by ESTCP, EOD/LIC (the government), and Sparta, with the government investing $1.3 million and Sparta investing $2.5 million. The government purchased the laser device, and LPS provided for the development of the beam expander and the optical bench, provided for the integration of the laser device into LDS, and provided for the integration of the laser power and laser device subsystems into the HMMWV. Sparta developed the AVS, BCS, LCS, PPS, and FCS. Multiple attempts at purchasing and installing a reliable working laser occurred. A reliable, working laser purchased by the government never materialized during this demonstration project. The current working laser was purchased by SMDC for their effort and they graciously allowed the demonstrations to happen with the government laser being used as a spare. All attempts to achieve a working laser encroached on the proposed funding for the demonstration and, as a result, the amount of testing being done decreased from what was originally planned.

5.2.2 Explosive Operations

The explosive operations costs were considerably less than the cost of the equipment. The primary costs include labor, travel, some materials, and the cost of using the range. For scenario 1 testing, there was the added cost of analyzing soil samples. The costs of using the range were different for each scenario. RTTC range costs included support costs such as target inventory, civilian range management, contracted range support personnel, contracted media support personnel, and base-provided emergency personnel. These costs were part of a flat fee of $25,000 per day for 5 days. (Saturday was not charged to the program due to cancellation of an entire day for weather.) NTTR costs included range management, one EOD support technician, base-provided emergency personnel, and use of a storage garage. These costs were not charged to the program but are inherent in the cost of performing operations. Labor costs included the test director ($8,000), and 4 or 5 Sparta personnel ($40,000). Travel costs included trips to RTTC and NTTR for the test director ($3,000) and trips to NTTR for Sparta personnel ($8,000). Travel to RTTC was not considered since both Sparta and RTTC are in Huntsville, Alabama. Materials used for both scenarios were practically negligible. They consisted of fuel for the H-LONS and generator and videotape ($1,000). The last cost element of the explosive operations was the soil sample testing for $8,500 and included the analysis and all the material necessary to collect the samples, such as collection vials, collection pans, and scoops.

5.2.3 Maintenance

Maintenance costs affected the demonstration. The laser performed well during the demonstration, but the HMMWV required numerous maintenance procedures. During the RTTC tests, most of the maintenance procedures, such as fixing the air conditioning, were performed by Sparta personnel between days of testing during overtime hours. This cost was absorbed in the cost of the contract but is inherently present. Also at RTTC, the jitter problem caused by the beam expander was addressed by phoning technical support during range hours, burning range costs with no testing being performed. At NTTR the HMMWV suffered a flat tire. No spares were present when the testing occurred so operations ceased until a spare tire and jack could be obtained. The new tires and jack cost $1,500. Also at NTTR, the HMMWV suffered a broken

windshield. This was not replaced but would be considered a likely maintenance occurrence during normal range operations. The estimated cost of replacing the windshield is $5,000. Based on these two occurrences in a week, it is logical to assume that flat tires, broken windshields, and other similar hazards of performing ordnance neutralization could occur frequently. Therefore, it is appropriate to estimate maintenance costs at approximately $100,000 or more per year.

5.3 COST COMPARISON

Comparing costs of clearing an active range with the total costs of this demonstration and the current method is not very meaningful, primarily because of the capital cost of the equipment and the RTTC demonstration, which is a research-type effort that would not be duplicated under normal range clearance operations. But comparing the cost of the NTTR portion of the demonstration, assuming the H-LONS is already a tool in the EOD units' arsenal, is meaningful.

Table 9 below summarizes the major costs of performing range-clearing operations like those performed at NTTR with the H-LONS and the current method. The data for the traditional method are actual numbers from an operation performed by nine EOD technicians for 2 weeks, resulting in 2,451 items neutralized. The H-LONS data is a combination of actual data taken from this demonstration and hypothetical assumptions, such as if the operation were performed by three EOD technicians rather than Sparta employees.

Table 9. Cost Comparison of H-LONS and Current Method.

Cost Category	H-LONS ($)	Current Method ($)
Medic H-LONS: 24 hours Current: 80 hours	1,440	4,800
Labor H-LONS: 72 man-hours Current: 720 man-hours	4,320	43,200
Vehicles: H-LONS: 1 @ 3 days Current: 3 @ 10 days	320	2,508
Per Diem	128	1,155
Travel	103	926
Fuel	150	70
Supplies	78	78
C-4*: 1,320 @ $23	0	30,360
Igniters: 1,200 @ $3.28	0	1,632
Detcord: 5,000 ft @ $0.10	0	500
Time fuze: 9,023 ft @ $0.14	0	1,265
Spare parts	1,500	0
Total	8,039	86,494
Cost per neutralization**	20.00	35.29
Cost, including estimated amortized ZEUS costs	31.00	

*NTTR divided a block of C-4 into thirds

**The demonstration neutralized 402 targets, and the current method neutralized 2,451.

Table 9 shows that H-LONS neutralizations cost less per neutralization than the current method. This table is a comparison of 3 days of neutralization for H-LONS versus 10 days of the current

method. A cost of \$60/hr is used as an average cost of military manpower. The parameter of cost per neutralization is a valid comparison regardless of the different length of the operations. If we include an estimated production cost of \$400,000 for the ZEUS system, a \$50,000 shot lifetime, and \$100,000/yr maintenance cost, approximately \$11/shot is added to the per neutralization cost, still lower than the current method.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The primary deviation from estimated costs was that reliable laser diodes were not available for a long period of time and eventually not at all from the original vendors. Most of the budget was spent in trying to get the H-LONS system to function properly and reliably, leaving less for demonstration tests. Continued work on Laser diode reliability has taken place since this demonstration project and may impact future costs.

6.2 PERFORMANCE OBSERVATIONS

During the demonstration, several observations could be made regarding the performance of the H-LONS. First, the H-LONS works best when the operator knows where the targets are in advance. Since it is very difficult to look for targets using only the onboard camera, some kind of surveillance is necessary. Next, the H-LONS experienced some jitter in all scenarios. A quick field solution of powering down and resetting the system was implemented. The laser performed well during the demonstration, but many nuisance problems occurred with the vehicle. The air conditioning system failed at RTTC, a flat tire occurred at NTTR, and the vehicle suffered a munition fragment hit in the windshield at NTTR. Therefore, it would be prudent to have available a healthy supply of vehicle-related spare parts and accessories, such as a removable protective windshield steel plate, and skilled mechanics. This could also affect the operating costs of the equipment.

LNS does not provide the expected benefit of reduced explosive contamination in the soil. The opposite occurs; more explosive residue is created. This agrees with the findings of low order explosion work being conducted at NAVEODTECHDIV and elsewhere. However, low order reactions cause much less physical damage to the environment (i.e., a smaller crater or no crater), and the metal scrap from the UXO is much easier to collect after such events.

6.3 SCALE-UP

Since the H-LONS is a one-of-a-kind vehicle, it is believed that initial costs of the system would drastically decrease when more systems were built based on economies of scale and lessons learned along the way by the contractor in building the current system. Also, the technology is in its infancy, suggesting that later iterations will cost less or have more capability.

6.4 OTHER SIGNIFICANT OBSERVATIONS

The primary factor that affects implementation of this technology other than cost is that it is a radical departure from the traditional method of neutralizing ordnance. This technology is the most promising technology to neutralize ordnance without an EOD technician setting foot near the ordnance.

6.5 LESSONS LEARNED

The primary lesson learned was that we overestimated the maturity of the laser diode manufacturing capability of producing reliable diodes. We had to wait for a vendor to be able to produce reliable diodes before we could begin the demonstration. The end result was that the demonstration was delayed for more than 2 years.

6.6 END-USER ISSUES

The primary issue for end users, mainly EOD units or UXO environmental remediation firms, is the initial cost of fielding the system. A laser neutralization system would be the most expensive piece of equipment used by any EOD unit. When the training costs are added, to be proficient and maintain an up-armored HMMWV, especially one used exclusively for laser negation, the system is beyond most units' current fiscal boundaries. Because the technology is in its infancy, costs could eventually decrease while the capabilities could increase.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

There are no regulation drivers promoting or hindering the use of LNS. While there are approvals required for laser use, the procedures to obtain those are known and do not present an obstacle to LNS technology implementation. The increase in explosives residue may require additional testing and mitigation or may limit the applicability of this technology on some sites, depending on local conditions and relevant environmental regulations.

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APPENDIX A

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CMSgt Dennis Hakenburger	Nellis AFB EOD Flight 8355 Bergstrom Avenue Nellis Air Force Base, NV 89191-6112	(702) 652-1414 ernest.lorelli@nellis.af.mil	Primary operators and will provide main demonstration site and facilities
Robert J. Valis	USACHPPM MCHB-TS-LID (Sample Management Laboratory) Building E2100 APG, MD 21010-5403	(410) 436-8271 robert.valis@apg.amedd.army.mil	Responsible for soil sample analysis
Thomas A. Crutcher	RTTC CSTE-DTC-RT-F-FL Building 6301 Huntsville, AL 35898	(256) 842-2745 tcrutcher@rttc.redstone.army.mil	Primary operators and will provide main demonstration site and facilities

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